Countdown for RADARSAT-2 System Operations

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***Abstract*- RADARSAT-1 has been operating for over nine years as the world's first commercial space-borne synthetic aperture RADAR (SAR) remote sensing system. RADARSAT-2 provides for a continuation of the RADARSAT-1 services, enhanced performance, new features, and a more commercial approach to both the development and operation of the system. This paper describes some key aspects of the development from an operations perspective along with the system integration and preparation for operations.**

Following a system operations overview, constraints, driving requirements, and mission characteristics determining the operations concept are described. Operations lessons learned from RADARSAT-1 system development and operation and factored into the RADARSAT-2 approach are summarized.

Organizational and technical challenges and solutions for development and system operations are explored using RADARSAT-2 examples.

A key challenge is to perform the system integration for RADARSAT-2 without interference to continuing RADARSAT-1 operations. The paper describes the phases, major activities and milestones of the system integration, and key features of the operations preparation for the system components.

I. INTRODUCTION AND SYSTEM OVERVIEW

RADARSAT mission objectives are to:

- ensure continuity of RADARSAT data and products beyond RADARSAT-1;
- commercialize the operations of the RADARSAT program;
- ensure data availability for environmental monitoring and resource management;
- support Canadian Government operational programs requiring regular SAR data;
- collect SAR data for approved research studies sponsored by the Canadian Government; and to
- collect and make data available to persons on a non-discriminatory basis.

RADARSAT-1 has provided close to 10 years of operational experience in accepting orders and delivering data to commercial users, many in a Near Real Time (NRT) environment. A viable business has been built to service regular monitoring customers, many of whom require data and information products quickly. The current business out of the Canadian Processing facility alone, processes more than half the volume of data requests in near-real time (under 4 hours from acquisition to delivery). This has provided valuable experience in servicing an operationally oriented customer base. It has also provided a base of market expectations that were critical in the development of the RADARSAT-2 program.

The RADARSAT system comprises RADARSAT-2 space and ground segments, operations and business management functions, along with existing RADARSAT-1 segments, which together will provide earth observation data products to

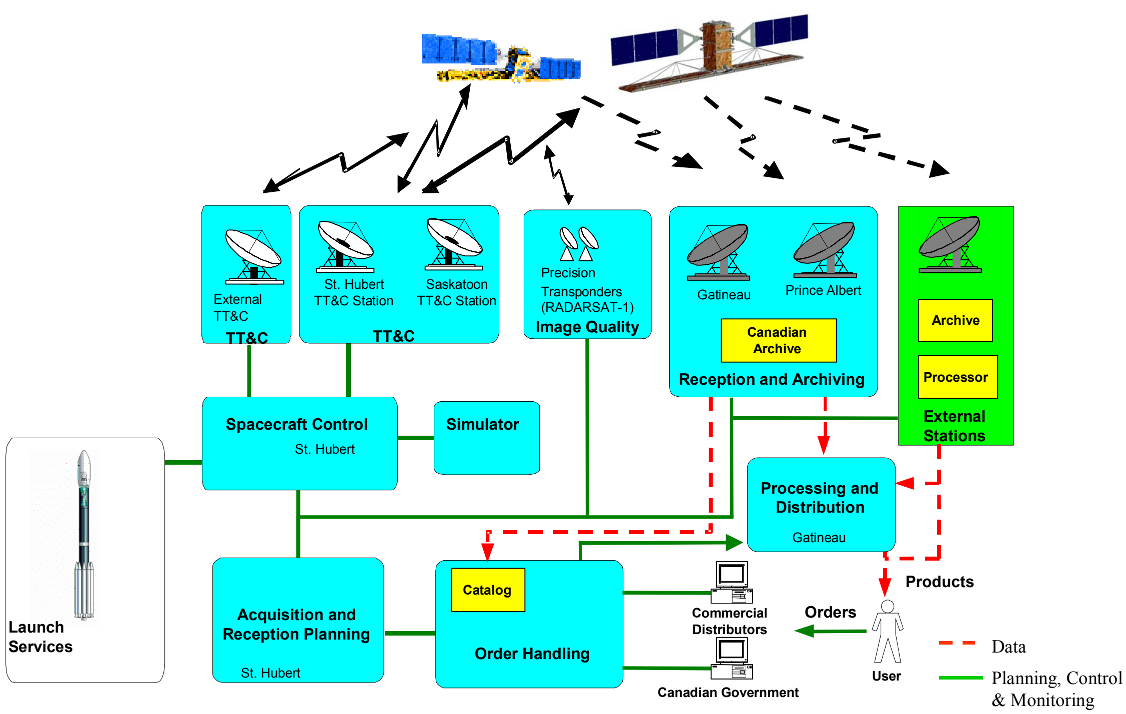

Figure 1 RADARSAT Mission Operations Overview

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distributors and end-users. The operations and business management areas will be responsible for the operation and business exploitation of the system after RADARSAT-2 commissioning. The overall system is illustrated in Figure 1.

The space segment comprises the RADARSAT-2 spacecraft and launch services. The spacecraft is a 3-axis stabilized satellite with bus module and a SAR payload module to provide the active radar.

The ground segment provides the ground software, hardware and communications infrastructure to support all operations phases. Ground segment subsystems comprise:

- Spacecraft Control;
- Telemetry, Tracking and Command;
- Order Handling;
- Acquisition and Reception Planning;
- Image Quality Control;
- Reception and Archiving;
- Processing and Distribution, and
- Spacecraft Simulation.

Operations personnel operate and maintain the RADARSAT-2 spacecraft and ground segment to satisfy user requests, from order receipt through to generation and distribution of products; to maintain the health and safety of the spacecraft; and to maintain system performance.

The RADARSAT-2 spacecraft will be inserted into the same Sun-synchronous frozen orbit as RADARSAT-1 and phased so as to follow the same ground-track, offset in time, and to permit shared use of ground TT&C and X-band data reception resources, for as long as RADARSAT-1 operations continue. As with RADARSAT-1, RADARSAT-2 in-orbit operations will comprise LEOP, Commissioning, and Routine Phase operations. Commercial (Routine Phase) operations will commence nominally three months after launch and last for seven years.

A more comprehensive RADARSAT-2 overview is available on the MDA web-site at:
http://www.mdacorporation.com/systems/radarsat2.shtml

II. DESIGN DRIVERS AND FEATURES

RADARSAT-2 flies in a “dawn-dusk” (98.58° Inclination, 18:00 hours Right Ascension) operational orbit at about 800 km altitude. The orbit eccentricity and argument of perigee are controlled through periodic drag make-up manoeuvres to keep the orbit “frozen”. The burns are also timed to maintain a specific 343 orbits 24 days repeating ground-track within required tolerances. Infrequent inclination maintenance burns are also budgeted.

For the RADARSAT-2 TT&C ground stations in southern Quebec and northern Saskatchewan, the operational orbit provides for two daily periods where the spacecraft is visible to the TT&C station on successive orbits, called “pass groups”. Planning timelines are constructed around the pass groups to reduce the minimum latency time between order placement and uplink of command loads to the spacecraft.

The spacecraft design provides for highly autonomous operations, with the operations focus during the Routine Phase around twice-daily command loads to support imaging operations. With on-board GPS for orbit determination, ground orbit processing generates definitive orbits for image processing and predicted orbit products. The spacecraft Fault Detection, Identification, and Recovery (FDIR) system provides on-board health and status monitoring which can lead to autonomous switching to two recovery levels in the event of detected anomalies.

For the critical Solar Array Wing and SAR Antenna appendage deployment activities during the Launch & Early Orbit Phase (LEOP), the Canadian TT&C sites will be supplemented with the Kongsberg Satellite Services (KSAT) Svalbard Station in Norway. The combined network can provide for at least one pass per orbit. A combined operations team of Routine Phase staff supplemented with development personnel will handle the LEOP and commissioning activities.

A key consideration throughout development has been how to contain operations costs consistent with acceptably low operations risk. Cost metrics established early in concept development have given targets as requirements.

The need to bring the RADARSAT-2 system on-line without interference to on-going RADARSAT-1 operations has influenced ground segment design choices and plans for system integration.

III. LESSONS LEARNED FROM RADARSAT-1

For RADARSAT-1 system development the market expectations were not known to the same degree as today, therefore the technical solution drove the system and operational capability. The key operational input during development was from the Canadian Ice Services. Having this input has allowed the business to meet the near-real time processing requirements to which the core of the business now focuses.

RADARSAT-2 has benefited from RADARSAT-1 market knowledge, both in system design and operations planning. This includes customer desire for increased resolution, increasing need for ordering confidentiality by customers, improved deadlines in order submission, more efficient order management to key large customers, to name a few.

Both ground segment and operations have been designed to address market driven improvements from inception. To remain commercially viable, attention was paid to keep operations cost to a minimum, while improving overall responsiveness. Further attention was given to flexibility to adapt to changing market demand, and the needs for customer feedback and confidentiality of information.

RADARSAT-1 ground systems were built around a centralised Mission Management Office (MMO) with access from five distributed order desks. MMO covers a large set of functionalities such as ordering, acquisition and reception planning, and generating work order for the production system. While reducing the number of interfaces, this concept leads to added system complexity and bottlenecks. The complexity and lack of design flexibility often led to work-around solutions to solve operational issues. RADARSAT-2 ground segment design utilises standard MDA components where applicable and new system developments leveraging the

RADARSAT-1 operational experience. The modular approach for subsystems such as order handling, acquisition and reception planning, etc., facilitates implementation of corrective and adaptive maintenance. It also facilitates operations efficiency by helping to avoid unnecessary bottlenecks. For example, currently, requests for RADARSAT-1 archive data involve the central planning system (MMO) adding delay and operations cost. For RADARSAT-2, the archive order passes directly from the ordering system to the processing system. The processing operator will see the work order being processed within minutes of the archive order submission.

The RADARSAT-1 experience is also leading to improvements in order placement and tracking for RADARSAT-2 through the concept of distributing the ordering process among operational agencies. For large volume users, a distributed ordering system will allow these customers to place and track their orders from acquisition to production and delivery. This allows a customer, who best knows their needs, to appropriately react to any problems occurring during an order's life cycle. This was made possible using web technology, and the notion that each ground segment system reports the progress of an order back to the originator. Customers with system access will know in real time the status of each order element. By empowering the user with the timely information they need, operational overhead is reduced.

To respond to customer needs, remarkable flexibility has been built into the RADARSAT-2 system design, from the satellite capability to select beam modes to the product delivery options. Using GEOTIFF and XML header information in the product format promotes easy use of the data in most popular image processing/GIS and graphics software packages. The ability to vary the SAR antenna beam mode/polarization selection from the ground provides the capability to address evolving customer demands for image product requirement changes with the satellite baseline design.

IV. DEVELOPMENT CHALLENGES AND OPPORTUNITIES

RADARSAT-2 as a privately owned satellite has entered Canada into a new legislative regime. As a signatory of the Outer Space Treaty of 1967, governments are provided the freedom to use and explore space on a non discriminatory basis and in accordance with international resolutions. Commercial space activities are allowed on condition of state supervision. Canada, and other countries are choosing to enact legislation, regulations and licensing procedures to meet this obligation. RADARSAT-2 is Canada's first privately owned and operated earth observation satellite, and as such has become the reference for the development of this legislation. Developing the ground segment in parallel with the legislation has been an interesting challenge. The ground segment design has flexibility to allow for varying levels of regulation requirements in areas such as data encryption, protection of raw data, and ordering procedures. One positive advantage from the compliance to these regulations has been the opening of business opportunities to meet the more stringent security requirements of some potential customers.

The S-Band command uplink will be operated encrypted for normal operations. This introduces some procedurally intensive key loading and management activities.
The X-Band data downlink is also protected by encryption. Downlink key distribution for decryption uses a public/private key mechanism. This is robust, secure, and well understood. As an example of a challenge which has eased over time, the use of tunneling communications over commercial carrier infrastructure and even the internet, was state of the art early in the system design but is now standard practice.

The spacecraft agility to slew so as to image to the right or left of the sub-satellite point adds a new level of complexity to the development of long-term tasking plans. In order to manage the slewing the choice has been made to primarily use this option strategically. Areas of greatest customer interest for repeat monitoring operations, long-term or seasonal, will be built into a long-term slew plan. More tactical requests for slew variation will be evaluated based on the effect on already submitted acquisition requests.

To meet the cost and system adaptability targets, the system design has avoided constraining operational and operating characteristics of the space and ground segments. This led to the need to capture a large amount of system configuration information within these segments and a challenge to maintain data consistency. In the space and ground segments, the rationale and source of a configuration value is documented along with the value itself. This practice provides important decision making information when adapting the system throughout the operational phase.

Another practice to provide consistency in the system has been to architecturally centralize the spacecraft database into a single repository and to provide import and export mechanisms to and from this repository. This ensures consistency for the 20,000 telecommand and telemetry parameters in their definitions and instantiation in various forms within the system.

Development of the spacecraft flight operations procedures and databases from the operations plans, from supplier inputs and information on how the spacecraft works, and from an understanding of the ground segment tools to be used to conduct operations constitutes a major operations development activity. We are using this opportunity for "on-the-job" training for staff in the eventual Routine Phase operations team, and for early "usage" testing of the ground segment.

Through-life mission operations cost metrics have been monitored throughout development and used, as a system performance metric, in investment decisions on ground segment automation levels and to assess cost impacts of operations organization and subcontracting arrangements.

The desire to build the business based on flexibility and customer service poses further challenges. The standard published set of imaging modes is not expected to be a static list. Managing the imaging choices and changes throughout the life adds complexity to the day-to-day operations. The challenge provides the opportunity to best match the ever changing requirements for information products and to respond to increasing competition.

V. SYSTEM INTEGRATION

Impacts on continuing RADARSAT-1 operations are being minimised by installing ground segment equipment and testing early, to give maximum flexibility to co-ordinate involvement of operations and maintenance staff in test and training activities. Parts of the new data reception, processing, and archiving systems are also capable of multi-mission support, enabling operations staff to gain experience using them with existing missions in addition to RADARSAT-2 preparation.

The major system integration activities and milestones are shown in Figure 2. In this period, the focus of the program changes from the design and development of individual components, through their integration, test, and preparation for operations, to LEOP operations and system commissioning. The key activities are summarised below:

Spacecraft Assembly, Integration & Test. Some important overall system level tests and opportunities for validation of operations materials take place during Assembly, Integration, and Test (AIT) of the spacecraft. On RADARSAT-2 commonality between the spacecraft control system and the electrical ground support equipment (EGSE), used for system level testing of the payload, allows "flight" like procedures and databases to serve ground test and flight operations purposes. The operations validation activities involve flight control procedures and databases, and the use of planning products generated from the ground segment, run against the spacecraft using ground segment command and control components. The AIT campaign continues at the launch-site, with the Flight Readiness Review (FRR) signifying readiness for final launch preparation, once the spacecraft has been installed on the rocket.

Ground Segment Integration & Test. Integration and test of ground segment subsystems in the factory, system-level testing, and on-site installation and testing provides opportunities for devising operationally realistic test scenarios, and for "on-the-job" training participation of operations staff in the test preparation, conduct, and trouble-shooting. This smoothes the transition of the ground segment from development to the operations phases.

Operations Integration & Simulations. Integration and tuning of operations materials, such as automated procedures and operations databases, in the installed ground segment, system testing involving operations personnel, and the completion of operations and maintenance training lead to the simulations campaign. Exercises provide for operations usage of the system and promote operations participation in the system testing. Rehearsals focus on staff readiness. The Operations Readiness Review (ORR) confirms readiness of the operations team, operations infrastructure, and ground segment, to support flight operations.

LEOP and Commissioning Operations. The critical initial TT&C acquisition, appendage deployments, and initial orbital correction burns are completed during LEOP. The system integration activities conclude with system commissioning, an incremental series of tests of the spacecraft bus, payload, image quality, and system performance, including system scenario checkout similar to planned routine phase operations. The Commissioning Review confirms readiness of the system for routine phase commercial operations.

VI. CONCLUSIONS

New RADARSAT-2 features and a changed regulatory climate are giving new challenges for the system and operations preparation, along with new commercial opportunities. RADARSAT-2 system operations will build upon and benefit from the many years of successful RADARSAT-1 operations.

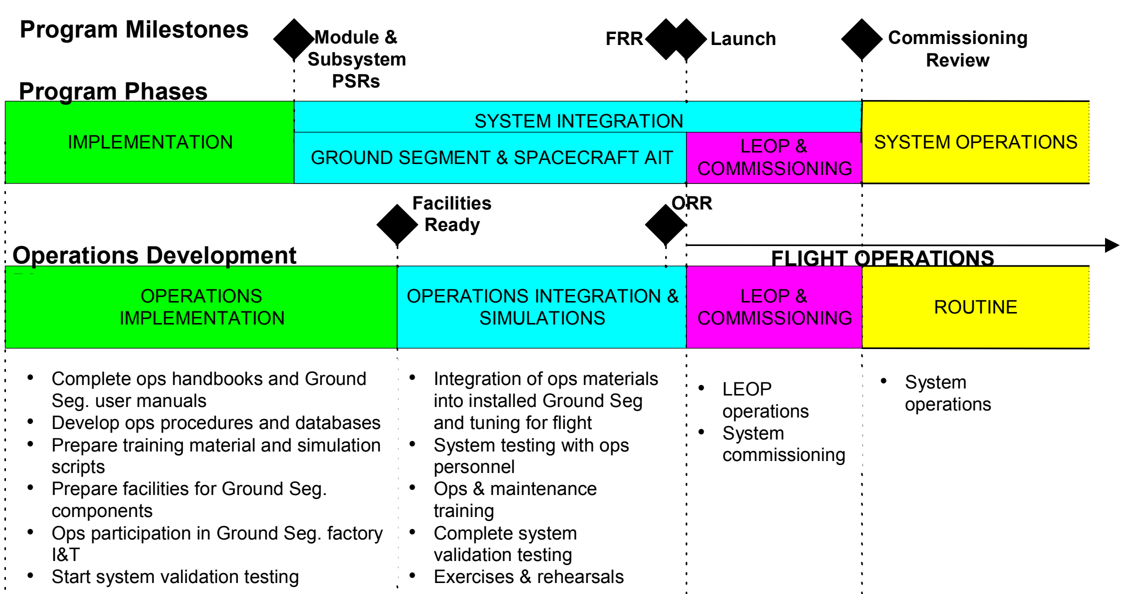

Figure 2 System Integration Activities